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THE EFFECTS OF LATERAL IMPACT ON CHILD DUMMY KINEMATICS AND CHILD RESTRAINT PERFORMANCE

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NOVEMBER 1, 1992

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Paper was presented at the 20th Annual Workshop on Human Subjects for Biomechanical Research. This paper has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.

Based on U.S. government statistics over 8000 side impact fatalities occur per year. In addition 24,000 serious injuries are recorded as a result of side impacts. As a result of the frequency and danger involved with this type of accident, the U.S. government has set minimum standards for passenger car protection in side impacts. This was accomplished through Federal Motor Vehicle Safety Standard (FMVSS) 214D.

In dealing with child occupant safety the only FMVSS standard which directly applies is FMVSS 213, Child Restraint Systems. However this standard addresses only frontal impacts in its testing procedures. This paper will detail a first effort to develop a child restraint side impact test procedure by combining various aspects of FMVSS 214D and FMVSS 213.

The FMVSS 213 test procedure places a child dummy in a child restraint located on a HYGE sled accelerator. Following a prescribed acceleration pulse, the sled is accelerated to reach a peak velocity of $30 \pm 0/-3$ mph for a standard compliance test. If a child restraint is tested in a misuse mode, the peak velocity is only 20 mph. For this experiment, the 213 acceleration pulse was used to achieve a peak sled velocity of 24.6 mph. This velocity was chosen to be midrange between the standard and misuse velocities previously stated. The velocity is also acceptable given vehicle lateral velocities in actual FMVSS 214D tests.

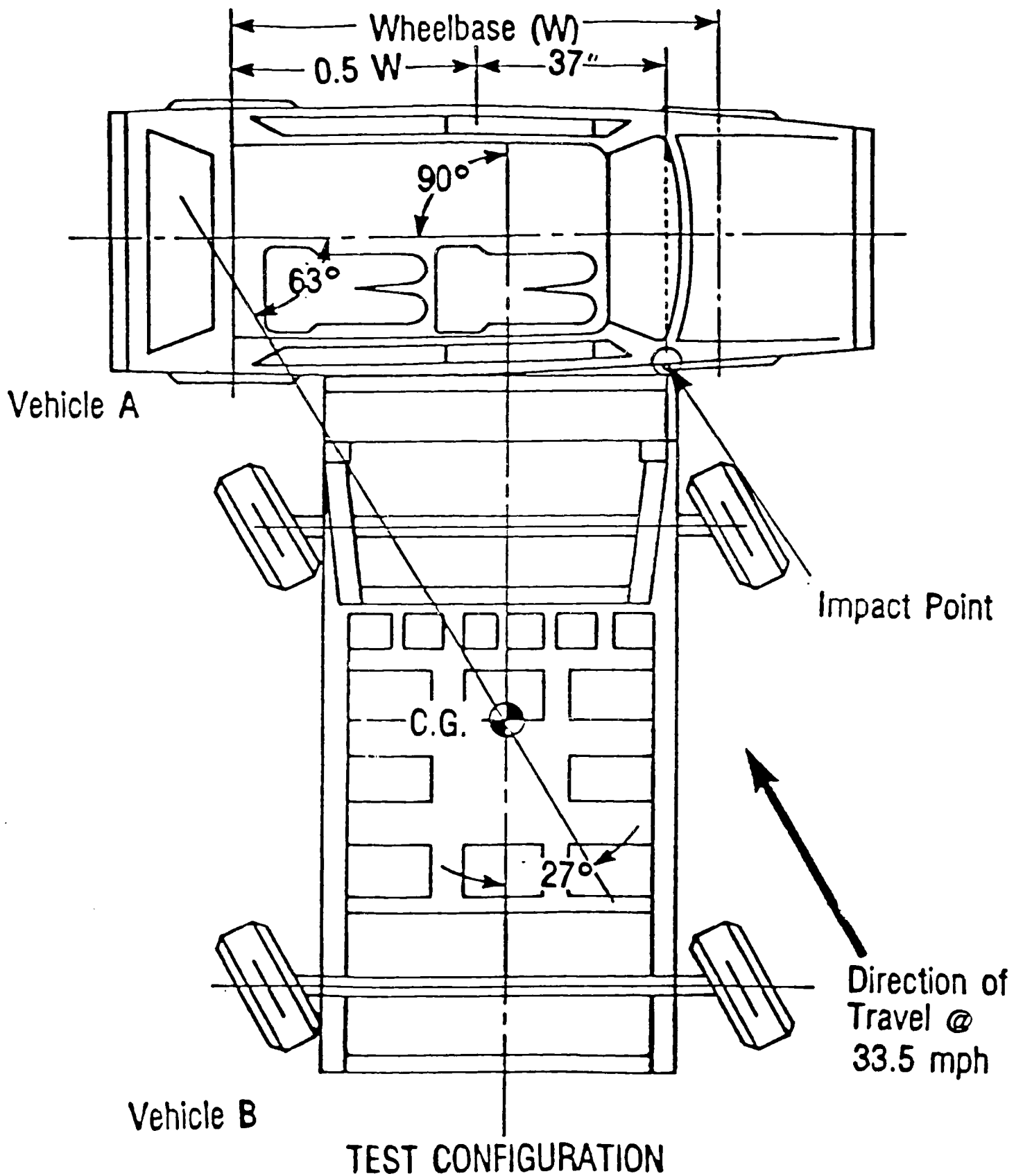
Other aspects of FMVSS 213 were also used. These include using the standard bench seat, automotive seat cover, and foam seat cushion. In addition, the child restraint was positioned in the center of the bench and secured in place with a type 1 lap belt.

The child restraint performance was obtained by using 6 month old, 3 year old, and 6 year old size dummies where applicable, analyzing high speed film of the event, and post-test evaluation of the child seat. The 3 year old and 6 year old size dummies were instrumented with triaxial accelerometers in the head and chest. The infant size dummy was not instrumented.

Instrumented child dummies provided both Head Injury Criterion (HIC), and 3 millisecond clipped chest resultant data. The 213 requirement is for HIC to be below 1000, and 3 msec. clipped chest resultant data be less than 60 g's. High-speed film analysis was performed to determine torso retention and maximum dummy head excursions. Head excursions are required to be behind a 32 inch line referenced from the bench seat back pivot point. In addition to the dummy kinematics and acceleration levels, the seat performance was assessed structurally. Pre/post test buckle release forces were measured, and the child restraints were inspected post-test for any structural failures as well as any change in seat back recline position that occurred during testing.

To make a first attempt at developing a realistic lateral impact sled test, the FMVSS 214D dynamic side impact test procedure was used. Figure 1, which depicts a right side impact, shows a crabbed 3000 pound moving barrier travelling at 33.5 mph striking the vehicle. The crab angle of 27 degrees simulates a 30/15 mph intersection accident where the striking vehicle forward velocity is 30 mph and the struck vehicle forward velocity is 15 mph. Given the design of a 214D test, the peak lateral velocity of the struck vehicle varies due to factors such as vehicle weight, stiffness etc. In a series of 214 side impact tests performed at Calspan the peak lateral velocity varied between 15 and 26 mph depending primarily on the struck vehicle weight. Given this range of lateral velocities, the proposed sled test velocity of roughly 25mph which was selected to be midrange between the FMVSS 213 standard and misuse test velocities seems acceptable. Lastly, one of the most important points to note in observing a 214D dynamic side impact test is that the struck vehicle side doors reach maximum intrusion into the interior of the vehicle *before* the vehicle reaches its maximum lateral velocity. Thus if interior head contact is the reason for the maximum 32 inch allowable head excursion in a FMVSS 213 sled test, the

Figure 1. FMVSS 214D Dynamic Side Impact Test Configuration



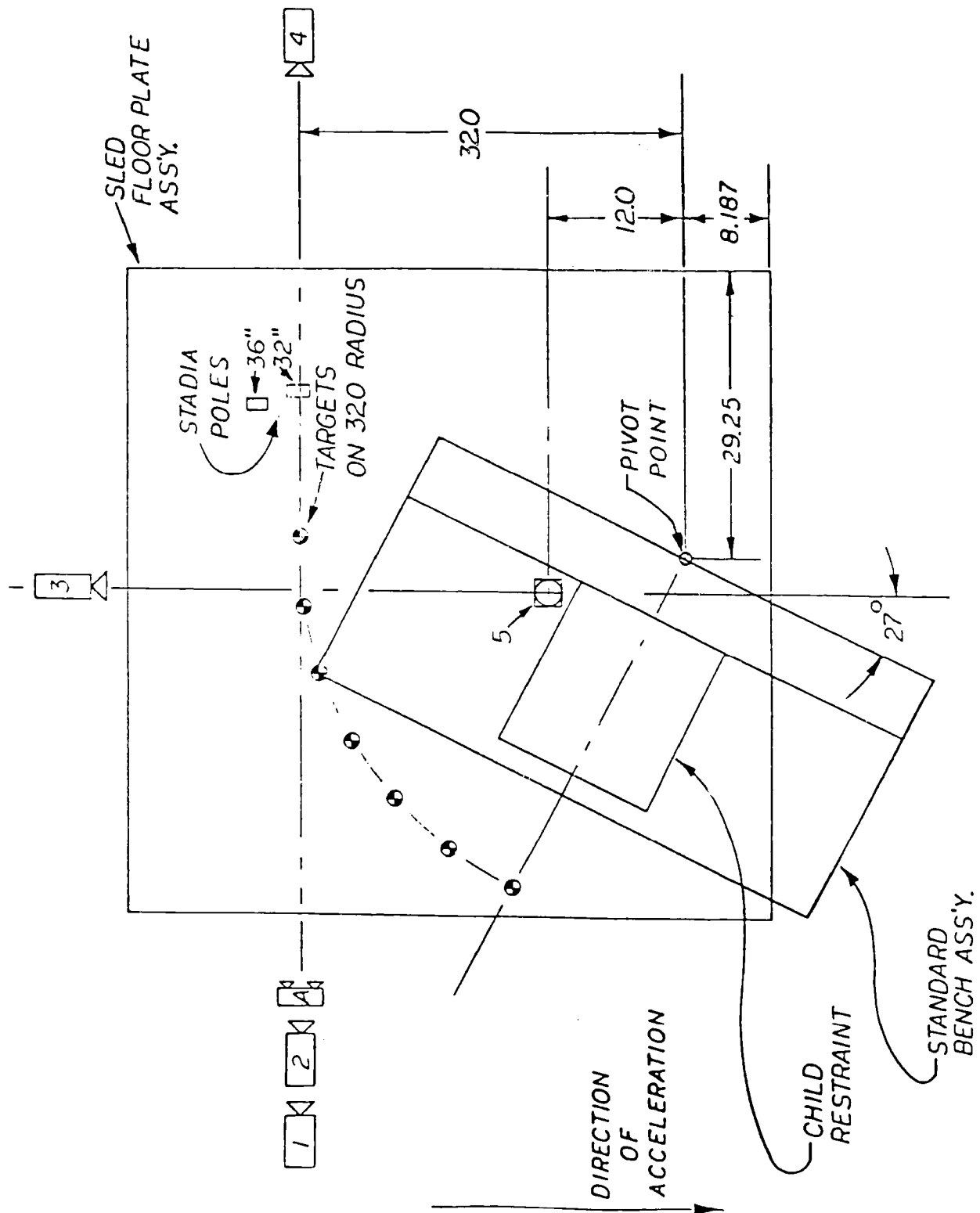
maximum allowable lateral head excursion should be determined by measuring the available vehicle interior space after the door is fully intruded.

Figure 2 shows a sketch of the sled test layout. The child restraint is centered on the bench seat which is rotated 27 degrees from the direction of sled acceleration. As in the 213 tests, the bench seat back pivot point at the centerline of the child restraint is taken as the reference for the 32 inch head excursion line.. Targets were placed on the sled at a 32 inch radius from the reference to coincide with the 213 maximum allowable head excursion requirement. On-board high speed cameras were mounted above the restraint, at the front of the seat, and at the 32 inch reference perpendicular to the direction of sled acceleration. The cameras were mounted on the sled to eliminate any possibility of film parallax.

Table 1 provides the test configuration. Three different types of child seats were used along with three different types of child dummies. The 6 month old size dummy was a 17 pound Cami infant. The 3 year old size was a 34 pound Part 572C dummy, and the 6 year old size was a 48 pound dummy. Each test condition used a dummy which was compatible with the child restraint selected. All child restraints selected for the tests had previously met the FMVSS 213 standard requirements. Seat installation on the sled was performed following manufacturer recommendations for direction (i.e. forward or rearward facing). Three repeat tests were performed within each of the four test conditions for a total of twelve tests in the program. As stated earlier, the peak lateral velocity on each on the sled tests was 24.6 mph.

Table 2 provides the mean data for each of the test conditions. In each case the HIC and chest G's were below the requirements set in FMVSS 213. The maximum head excursion exceeded 32 inches for both of the booster seat conditions. The maximum excursion of the seat back was measured for the infant seat because the dummy head was obscured by the seat. The

Figure 2. HYGE Sled Test Bed Configuration



high speed films of the rearward facing infant seats indicated the head of the dummy

Test Condition	Child Restraint	Dummy Type	Installation Mode
1	Infant Only	6 month old infant	rear-facing/reclined
2	Convertible	3 year old toddler	forward upright
3	Booster	3 year old toddler	forward upright
4	Booster	6 year old child	forward upright

Table 1 - Test Matrix

becomes trapped between the bench seat back and the child restraint when the restraint rebounds during the test. In all of the tests, the child restraints: retained the dummy torso, remained structurally intact, met pre/post test buckle release requirements, and did not change their recline position (if applicable) during the test event.

It may appear that lateral impacts do not pose a significant problem given the frontal head excursion requirements of FMVSS 213. However when examining the amount of lateral space available in a vehicle interior for head excursion, the distance is significantly less than the 32 inch mark used in 213 testing. Table 3 provides average estimates of available lateral interior space for non-impacted compact, mid-size and full size vehicles. The data was taken from a small sample of 1992 vehicles located at Calspan and was not meant to be comprehensive. By measuring from the vehicle interior centerline to an adjacent interior side at the seat height and mid seat back height, the lateral available space measurement was obtained. Comparing these

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Restraint/ Dummy	HIC	Chest Resultant 3 msec clip (gs)	Maximum Lateral Head Excursion (in)
Convertible 3-year old	510	31.3	29.7
Booster 3-year old	516	24.3	32.6
Booster 6-year old	968	25.5	34.2
Infant 6-month old	N/A	N/A	32.0*

**Seat back excursion*

Table 2 - Dynamic Data (means)

Vehicle Size/@ Mid-Door Fore-Aft Location	Mid Seat Back Height	Lower Seating Surface Height
Full Size/Rear Compartment Width from Longitudinal Centerline to Mid- Door (in)	29.3	29.7
Mid-Size/Rear Compartment Width from Longitudinal Centerline to Mid- Door (in)	28.0	26.3
Compact/Rear Compartment Width from Longitudinal Centerline to Mid- Door (in)	26.7	27.5

Table 3 -Average Rear Interior Compartment Dimensions

numbers to the measured excursion levels in table 2 shows contact would have occurred in all tests even if no interior intrusion occurred.

Table 4 provides data to estimate the amount of intrusion that may occur in a dynamic side impact test. The data was gathered from eight FMVSS 214D dynamic side impact tests performed by Calspan on 1987 and 1988 vehicles. Table 4 data was generated by measuring from the interior vehicle centerline laterally to a point on the vehicle interior door or side both pre and post test. The difference between the pre and post test measurements is the static intrusion. As was stated earlier, the dynamics of a side impact test are such that the maximum interior intrusion occurs before the peak lateral velocity of the struck vehicle occurs. Thus when the child dummy's head would move toward the struck side of the vehicle, the interior will already be intruded decreasing the amount of room available for non-conducting head movement.

Table 5 summarizes the previous data by subtracting the static intrusion in table 4 from the available interior space in table 3. Table 5 also restates the maximum head excursion measured in each of the lateral sled test conditions. When comparing the head lateral excursion with the available space after intrusion, head contact with the interior appears certain.

Table 6 presents a summary of results of the study and potential solutions to identified problems. One of the limiting factors in this study is the use of dummies which were designed for frontal impact testing. Likewise using the performance measure criteria of 1000 for HIC or 60 G's for a 3 millisecond clipped chest criteria may not be appropriate for a lateral impact. More research needs to be performed to develop validated child dummies and performance measures for lateral testing. In general all seats tested performed well from a structural point of view and also retained the dummy torso. Lateral head excursions must be examined more closely to determine what can be done to limited lateral excursion and/or protect the head should

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DATA FROM FMVSS 214D TESTS

Vehicle Size/Measurement Location	Window Sill Static Interior Intrusion (in)	Mid-Door Panel* Static Interior Intrusion (in)
Full-Size/Mid-Rear Door	8.8	9.1
Mid-Size/Mid-Rear Door	7.7	8.1
Compact/Mid-Rear Door	8.2	9.8

*Midway between sill top and bottom of the door.

Table 4 - Average Passenger Vehicle Rear Compartment Static Interior Intrusion

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Vehicle Size/ Mid-Door Fore- Aft Location	Mid-Door Panel	Restraint Type/ Dummy Type	Maximum Lateral Head Excursion (in)
Full Size/Rear Compartment Width From Longitudinal Centerline to Mid-Door Minus Static Intrusion (in)	20.2	Convertible/ 3-Year Old	29.7
Mid Size/Rear Compartment Width From Longitudinal Centerline to Mid-Door Minus Static Intrusion (in)	19.9	Booster/ 3-Year Old	32.6
Compact/Rear Compartment Width From Longitudinal Centerline to Mid-Door Minus Static Intrusion (in)	17.9	Booster/ 6-Year Old	34.2
		Infant/ 6 Month Old	32.0

Table 5 -Average Passenger Vehicle Rear Compartment Width Minus Static Interior Intrusion From Vehicle Longitudinal Centerline At Mid-Door Height. Average Maximum Lateral Head Excursion.

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	Summary of Results	Potential Solutions
1	Child restraint performance (structural integrity, Pre/post buckle release forces, torso retention, recline adjustment position) appeared to be satisfactory.	Verify results with further testing. Test other child restraint models.
2	HIC and chest clip data within frontal impact limits. Uncertain if appropriate for side impact.	Research needed to establish appropriate methods for measuring side impact forces.
3	Maximum lateral head excursion appeared to exceed lateral interior space in the vehicle rear compartment.	Research needed to establish a "safety zone" or envelope in which the child occupant's head can move laterally without striking the vehicle's interior.
4	Vehicle rear compartment is not wide enough to accommodate lateral movement of child occupant.	<ul style="list-style-type: none">-Extend width of child restraint base to increase stability.-Tether child restraint.-Design vehicle door to limit interior intrusion.
5	Adequate head and neck support may not be provided for infants during lateral impact.	<ul style="list-style-type: none">-Increase width of child restraint side support surface.-Extend width of child restraint base to increase stability.

Table 6 - Summary of Research Results and Potential Solutions

interior contact occur. Finally, infant head/neck support should also be investigated given the trapping of the infant dummy head between the child restraint and bench seat back seen in this program.

DISCUSSION

PAPER: **The Effects of Lateral Impact on Child Kinematics and Child Restraint Performance**

PRESENTER: David Travale

AUTHORS: Mary Lloyd, David Roberts, David Travale

QUESTION: Pat Kaiker, Chrysler Corporation

Do you have any incidence information from the field how many children have been injured in side impacts or what the side impact injuries for children are?

ANSWER: We don't have any information regarding that. I just looked in the 214 rule to find out the number of side impacts that occur and the feeling is that if you do have that number of side impacts, you're going to have children riding in the vehicle, so we decided it was an important enough issue to please do some preliminary research.

Q: I think there is some indication in the industry that the side impact law, as written, doesn't really reflect what happens in the field in side impacts, that it is more of a very rare type situation instead of a more common behavior that we do witness in the field and if that is true, it is quite possible that injuries to children might be a much lower incidence than we suspect. We should probably survey our NHTSA data bases quite carefully and any other data bases to see what the situation is before we keep continuing with experiments. I'm just recommending that we characterize real life.

A: I believe the numbers I read indicate about roughly a third of the accidents were side impacts and again, that's from the NHTSA information.

Q: Keith Friedman, Friedman Research

What was the restraint system that you used? Was it a lap belt?

A: It was just a standard lap belt that is used to restrain the child's seat 4F of the 213 test. It is just belting material and it is tensioned prior to the test. It is not a commercially available restraint system.

Q: Just one observation or one comment. I noticed in my own baby with rear facing seats that there is an interaction between the front of the rear facing seat and the front seats. This is a split seat arrangement. It's kind of an interesting solution for that car to couple the rear facing seat with the front seats or to keep the excursion from going off to the side. You might consider incorporating the front seat and then it's interaction with the rear facing seat.

Q: Don Friedman, Liability Research

I just wanted to mention, with respect to the question from Chrysler that two years ago at the ESB Conference, I reported on six real world infants in child seats that were brain

damaged or fatally injured in side impacts and those followed exactly your parameters, including the side-impact intrusion. The point being, however, that as you pointed out, the intrusion occurs first and if it is possible to incorporate, in the wings of the child seat, padding that would be appropriate for the rather soft structural skull of a child, that there is a possibility of mitigating those kinds of injuries because they do get it through the wing. If you had run the tests with the intrusion preset, you would have had some insight into what kind of hit you get and it is very high.

A: Thank you.

Q: Larry Schneider, University of Michigan

I wonder if you could comment about the softness of the padding in the 213 standard bench seat versus typical rear seats in vehicles today and what effect that might have on the excursions that you measured.

A: Well, I'm not directly involved in 213. One of our people here, Dave Roberts, I don't know if you can comment on that.

A: I'm not sure that it is necessarily realistic right now to give compression deflection characteristics of the 213 or is it realistic as compared to real automotive seats in use now. However, a number of tests have been performed using actual automotive seats presently in the vehicle. The data support bench seat resonance, so it's probably a good seat, but I don't know if the characteristics are exactly the same.

A: Yes, we tried to use the portion of both standards as just a beginning research method, so we decided to use the standard 213 bench seat.